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TIGHTENING HIGH-STRENGTH BOLTS

by F. P Drew, A.M. ASCE

STRUCTURAL DIVISION

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TIGHTENING HIGH-STRENGTH BOLTS

F. P. Drew,[1] A.M. ASCE

INTRODUCTION

It is not often that the demand for a product runs so closely on the heels of its research as seems to be the case with high-strength bolts.[2] Engineers, both in the field and the office, have been quick to apply this new tool, and the acceptance of these bolts as a structural fastener is becoming more and more general as the results of each research project add further promise of superior behavior.

Railroads have a particular interest in high strength bolts because they greatly simplify the problems of field maintenance and erection. The redriving of loose rivets constitutes a major proportion of the work of the railroad maintenance crew. Rivets, once replaced, may often be replaced several times thus adding to an already large maintenance schedule. It is no wonder, then, that high strength bolts have found their place in the railroad maintenance picture. Here is a fastener that will not loosen in service, yet can be installed without elaborate equipment. Quite often it is necessary to replace only a few scattered rivets at remote sites and to do so involves moving in equipment to heat and drive these few rivets. Replacing these rivets with high-strength bolts can be accomplished with ordinary hand tools, and the resulting fastener will prove to be more effective than the hot-driven rivet it replaced.

Much of the research and development of the high-strength bolt has been initiated by the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation. Since the formation of this Council in 1947 interest in the behavior of these bolts has mounted until today laboratory and field studies are being conducted by a great many separate organizations.

To be completely effective, high strength bolts must be tightened to at least the minimum bolt tension as prescribed in the Council's Specifications for the Assembly of Structural Joints Using High Strength Steel Bolts of February, 1954. The high clamping force applied to the joint permits little if any slip between the component parts. It is this feature of high strength bolts that makes them distinct from ordinary bolts and rivets.

Since the effectiveness of this type of fastener depends upon the clamping force developed the method of tightening the bolts is very important.

There are several methods in use at the present time for tightening high strength bolts, and some of these that are being used successfully will be described.

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1. Asst. Research Engr., Structures, Association of American Railroads, Chicago, Ill.
2. Bolts furnished to ASTM designation A 325-53T.

Present Method of Tightening with Hand Wrenches

Manual tightening can be best accomplished with a torque wrench. The Council Specifications give the approximate equivalent torque for required minimum bolt tension for the various sizes of bolts, so it is possible to apply the specified torque to a bolt by turning down the nut with a torque wrench. The torque is applied slowly and uniformly and the torque value read while the nut is in motion. If there are adjacent bolts to be tightened it is usually necessary to retighten those first installed since subsequent tightening tends to bring the bolted parts into a more solid bearing and loosen the adjacent bolt. Tightening a bolt with a torque wrench is no different than with a spud wrench. The torque wrench is only a means by which a known torque can be applied to a bolt. As with any hand wrench, if large bolts are to be tightened large wrenches are necessary. Hence torque wrenches are available in a wide range of capacities.

Present Method of Tightening with Impact Wrenches

Obviously, manual tightening will be confined only to those isolated locations where a few bolts are being installed, but where many bolts are involved, it is impractical to tighten each bolt manually and power equipment in the form of impact wrenches is necessary.

There are many sizes and makes of impact wrenches available today, but few manufacturers make wrenches capable of tightening 1 1/8, 1 or even 7/8 in bolts.

The characteristics of individual wrenches vary, but fundamentally each consists of two principal parts, a motor and an impact unit. The motor operates at a speed in proportion to the air pressure. The drive shaft of the motor is connected to a rotating hammer which imparts a rotary impact to an anvil, and the impacts from this anvil are transmitted to the nut to be turned through a closely fitting chuck. When the wrench runs free the chuck turns at its maximum speed, and no rotary impacts are created. But as soon as some resistance to the free running of the chuck occurs, the rotating hammer strikes the anvil, and the rate at which these impacts occur depends upon the type of wrench and the amount of resistance to turning. When the chuck is prevented from turning, the impacts continue at the maximum rate.

The present methods of using impact wrenches make it mandatory that they be calibrated because the output of a wrench is very sensitive to air pressure. A practical calibration device has been developed by the Bethlehem Steel Company. This particular device was designed to handle 3/4, 7/8 and 1 in bolts, but could probably be adapted to other sizes. It consists of a hydraulic ram and a steel yoke mounted on a steel frame. The device is shown in Fig. 1, where it is being used to calibrate an impact wrench. A bolt may be tightened in this calibrator either with a hand wrench or an impact wrench, and the bolt tension can be read directly on the pressure gage which has been converted to equivalent bolt tension.

In tightening bolts with an impact wrench and if a device of the type just described is used to calibrate the wrench, the following procedure is usually followed. The calibration device is set up in the working area such that the wrench can be calibrated with the same length of hose as will be used on the structure. This is important as a change in hose size or length will affect the pressure at the wrench. A sample bolt is placed in the calibrator. This bolt is of the size and length that will be used on the structure. The pressure

Fig. 1. Calibrating an impact wrench with a hydraulic calibrator.

Fig. 2. Using an impact wrench to determine the relation between air pressure, time and turns of the nut.

regulator is set at an approximate value and the wrench applied to the nut. The length of time required and the "feel" of the wrench is determined to tighten the bolt to the recommended bolt tension for calibrating wrenches as given in the specifications. The time element in this operation is probably not as important as the "feel" of the wrench when it is impacting at the required tension, however 10 seconds is considered a good operating speed. It is sometimes necessary to make several trials at different air pressures before the operator is ready to tighten bolts on the structure. This calibration is usually done at the beginning of each day or oftener, if there is a change in the set-up over that used in the original calibration, such as using a different bolt size, using another wrench (whether it is the same size and type or not), changing hose size or length, or other conditions which in the opinion of the engineer in charge would affect resulting bolt tension.

With his wrench calibrated the wrench operator is ready to tighten bolts on the structure. The bolt holes are lined up with drift pins and fitting-up bolts installed to bring the bolted parts together. The bolts to be used in the final connection are assembled and tightened with the impact wrench. The wrench is applied to the nut and impacting is continued until in the opinion of the operator, based on the calibration, the bolt is tight. If high strength bolts were used for fitting up, the wrench will be put on these nuts to determine, by the action of the wrench, whether further tightening is necessary. If special erection bolts were used for fitting up these are now removed and high strength bolts installed and tightened in the same manner.

If a check of the resulting bolt tension is desired, the torque required to move the nut in the tightening direction can be determined with a torque wrench.

While the use of a calibration device provides one means by which bolt tension can be controlled, it is not imperative that such a device be employed. Calibration of the wrench can be accomplished by tightening a sample bolt through some convenient solid plate material with the impact wrench and noting the time required and the "feel" of the wrench. With a bolt so tightened its tension is checked with a torque wrench. By adjusting the air pressure, or by impacting for a longer or shorter period on other sample bolts the required bolt tension can be obtained. In this type of calibration there is also large dependence placed on the "feel" of the wrench during impacting.

Development of One-Turn Tightening Method

In each of the aforementioned tightening methods which are in common use today special equipment and procedure are needed to effectively control the resulting bolt tension. However, it is not always possible to have these available, so a method is needed whereby high strength bolts can be tightened with whatever tools are immediately available and with the complete assurance that the bolts are adequately tight. With this conception in view, AREA Committee 15—Iron and Steel Structures requested the AAR to evaluate various bolt tightening procedures and to develop a method useful to railroad maintenance crews in particular. As a result of the AAR studies and tests a method was developed whereby turns of the nut from a "finger tight" position can be the criterion of bolt tension. The development of this method as well as some of the test results will be explained in what follows.

One-Half Turn for Minimum Bolt Tension

The Council's Specification establishes a relation between minimum bolt tension and corresponding approximate equivalent torque. If a bolt is tightened with a torque wrench to these prescribed values and the amount of nut turning recorded, it logically follows that another bolt like it can be tightened to the same tension by turning the nut the same amount.

Table 1 shows, for various sizes and lengths of bolts, the observed amount of nut turning to provide the required minimum bolt tension as prescribed in the aforementioned specifications. From this table it can be seen that 1/2 turn of the nut represents an average value for the complete range of sizes and lengths. The long bolts apparently require slightly more than 1/2 turn for minimum bolt tension, while the short bolts require slightly less. The length of the bolt, however, is not necessarily the principal factor in this turn differential. Since the long bolts were tightened through many plies of grip material, some extra nut turning was required to bring the plates into solid bearing. While the long bolts may elongate slightly more due to total elastic strain, most of the strain is restricted to the threaded portion, and for a given size bolt the length of this threaded portion is constant for all lengths up to and including 6 in. The character of the grip material seems to be the principal factor affecting nut turning up to minimum bolt tension. This is particularly evident by comparing the values in Table 1 for a 3-in solid slab grip with those for grip of plate plies.

The amount of nut turning was always measured from the "finger tight" or "hand tight" position. This is the amount of tightening which can be obtained by turning the nut by hand. This is considered to be a convenient reference position.

The fact that the 1/2-turn value applies equally well for the various size bolts tested can be partially explained by comparing the ratios of standard thread pitch to bolt diameter and the fact that most of the strain is restricted to the threaded portion of the bolt.

The standard length of threading is approximately two times the bolt diameter, and the portion of it within the grip distance, subject to high-tightening stress, is also approximately constant, in terms of bolt diameter. As will be seen in the following tabulation, the number of turns required to advance the nut one bolt diameter distance is likewise fairly constant.

Bolt Diameter	Threads per Inch	Threads per Diameter
5/8	11	6.9
3/4	10	7.5
7/8	9	7.9
1	8	8.0
1 1/8	7	7.9

When the bolt is tightened at or beyond its elastic proof load most of the resulting bolt strain takes place in the threaded portion and, for a given unit stress, is approximately proportional to the number of threads included in the grip, rather than to the total length of the bolt. Conversely, when the number of threads so engaged is more or less constant, the unit stress associated with a 1/2-thread pitch strain will have a sufficiently constant value for all practical purposes.

Turns of the Nut for Ultimate Bolt Tension

If 1/2 turn will insure minimum bolt tension, the amount of nut turning possible before failure should also be known.

High strength bolts manufactured in compliance with ASTM A325-53T may be expected to fail either by stripping of the threads in the nut or by breaking the bolt shank through the root of the threads. Table 2 shows for various sizes and lengths of bolt turns of the nut required to cause failure of the bolt either in breaking or stripping.

From this table it appears that 2 turns is about a minimum while 3 turns about a maximum, with an average of about 2 1/2. While it would be impossible to predict the number of turns for failure, 2 1/2 turns represents an average value for the complete range of sizes and lengths. At the ultimate bolt tension there appears to be no consistent relation between length of bolt and number of turns. Neither does the type of grip material have any effect on the number of turns to failure. The table also indicates that failure of the bolts by stripping or breaking is independent of the method used in torquing to failure; i.e., whether torque wrench or impact wrench is used.

Torque-Turn Relation for Ultimate Bolt Tension

Since many bolts were torqued to failure with a torque wrench, a record was kept of the relation between applied torque and turns of the nut.

Figures 3, 4, 5, 6 and 7 show how turns of the nut and torque are related up to the ultimate for each bolt size.

Friction characteristics of each individual bolt vary to such an extent that no two curves are alike, but there are certain significant features of these curves that should be brought out. In general, the curves rise to a maximum at about 1 1/2 turns and then either level off or fall to lower torque values. A point is reached where the nuts continue to turn without further increase in applied torque. This leveling off is probably due to necking of the bolt shank in the threaded portion. Another significant feature of these curves is their general sharp rise to 1 turn, and in many cases most of this rise is between 1/2 and 1 turn. Since clamping action or bolt tension and torque are closely allied, it appears from these curves that clamping action will not be substantially increased by turning the nut more than 1 turn.

In Figures 6, 7 and 8 the sharp fall of some of the curves at 2, 2 1/2 and 3 turns was due to stripping of the threads and a gradual failure. This is contrasted with the curves where the bolt broke, in which case the curve remained level or fell off but little.

One-turn tightening will stress the bolts in the plastic range. This was demonstrated by backing off the nut after one-turn tightening and observing about 1/2 turn of permanent set. Table 3 shows the results of measuring diameters before and after 1 turn-tightening.

One Full Turn

Even though 1/2 turn of the nut will produce minimum bolt tension several advantages can be realized by tightening to more than this minimum. These could be listed as follows.

1) These tests show that when the grip material is "soft" with many plies of material, 1/2 turn of the nut is insufficient to produce minimum bolt tension and additional nut turning is required. One full turn will insure that at least minimum tension is secured even with "soft" grips.

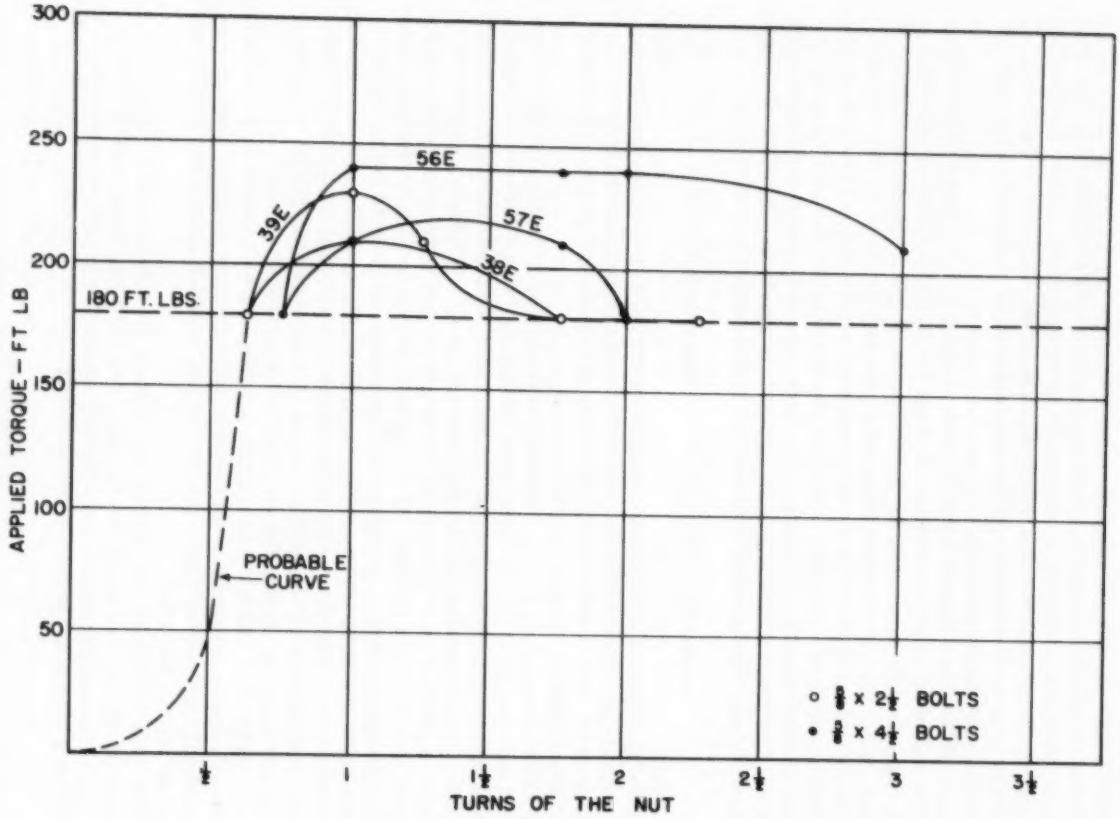

300
250
200
150
100
50
APPLIED TORQUE – FT LB
180 FT. LBS.
56E
39E
57E
38E
PROBABLE CURVE
○ ⅝ x 2½ BOLTS
● ⅝ x 4½ BOLTS
½
1
1½
2
2½
3
3½
TURNS OF THE NUT

FIG. 3

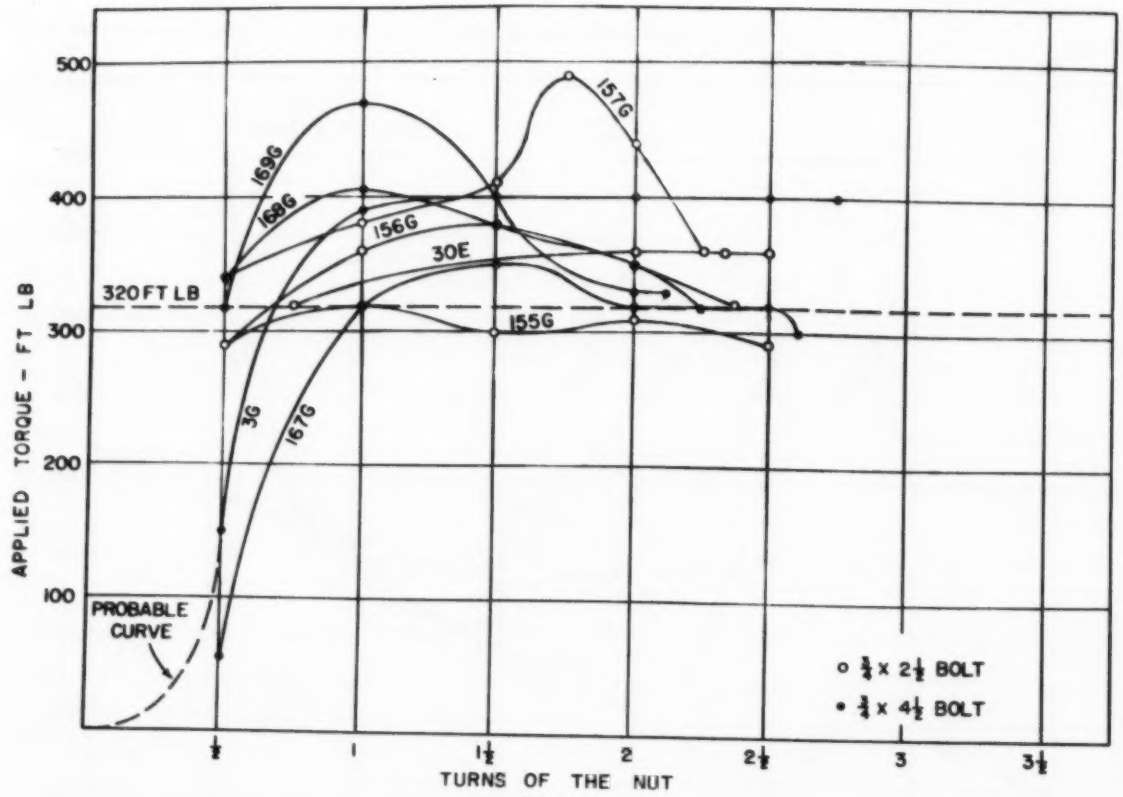

500
400
300
200
100
APPLIED TORQUE - FT LB
320 FT LB
PROBABLE CURVE
169G
168G
156G
30E
157G
155G
3G
167G
o ½ x 2½ BOLT
• ¾ x 4½ BOLT
½
1
1½
2
2½
3
3½
TURNS OF THE NUT

FIG. 4

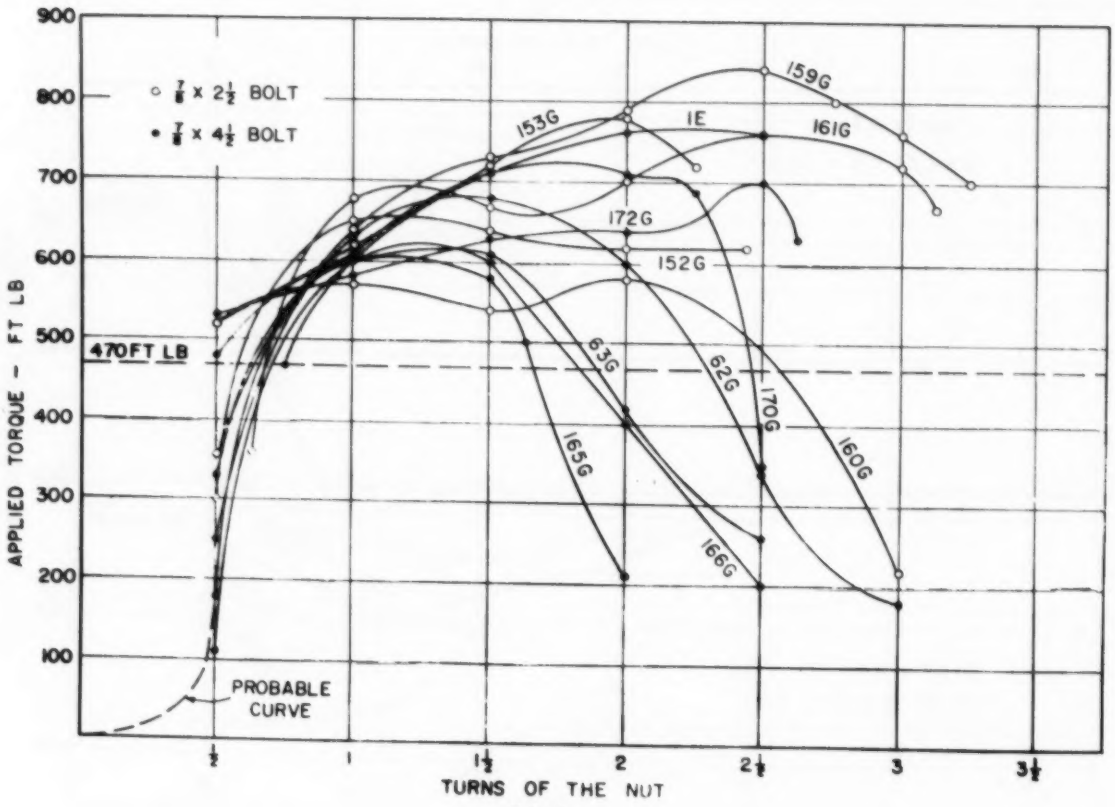

900
800
700
600
500
400
300
200
100
APPLIED TORQUE - FT LB
○ 7/8 x 2 1/2 BOLT
● 7/8 x 4 1/2 BOLT
470FT LB
153G
1E
159G
161G
172G
152G
63G
62G
170G
160G
165G
166G
PROBABLE CURVE
1/2
1
1 1/2
2
2 1/2
3
3 1/2
TURNS OF THE NUT

FIG. 5

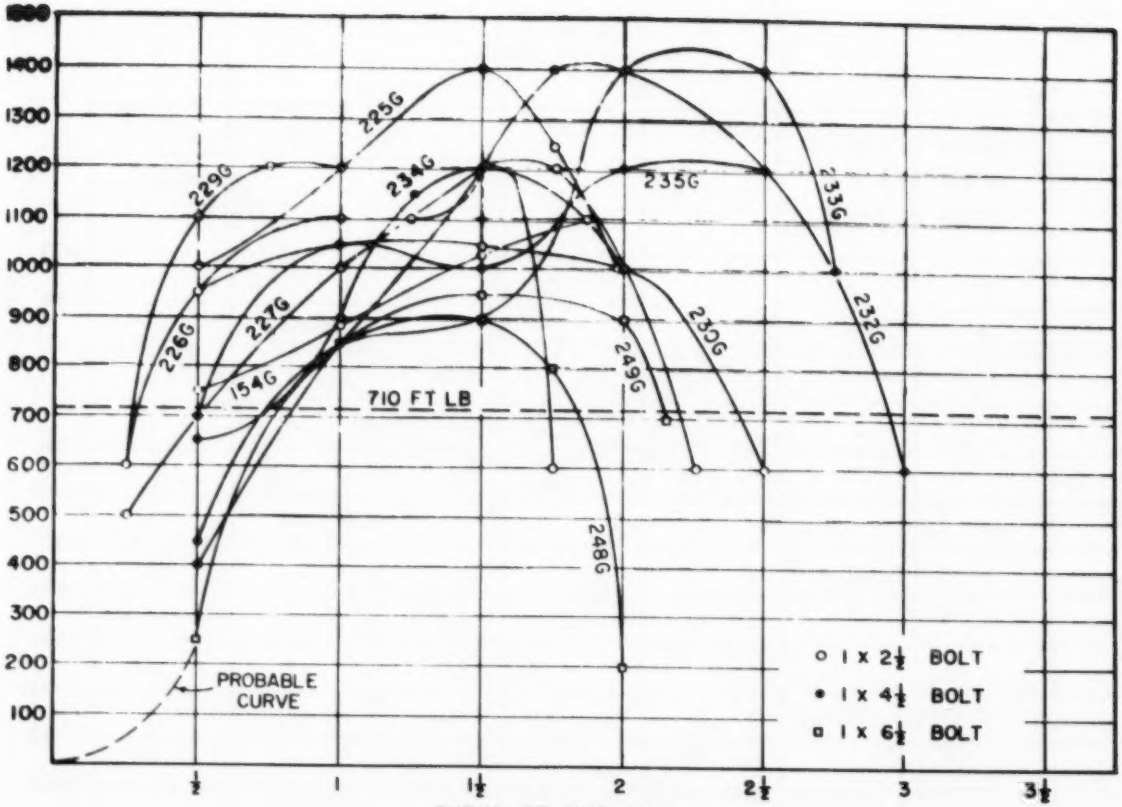

1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
225G
229G
234G
235G
233G
232G
226G
227G
154G
710 FT LB
235G
249G
248G
PROBABLE CURVE
1 x 2½ BOLT
1 x 4½ BOLT
1 x 6½ BOLT
½
1
1½
2
2½
3
3½
TURNS OF THE NUT

FIG. 6

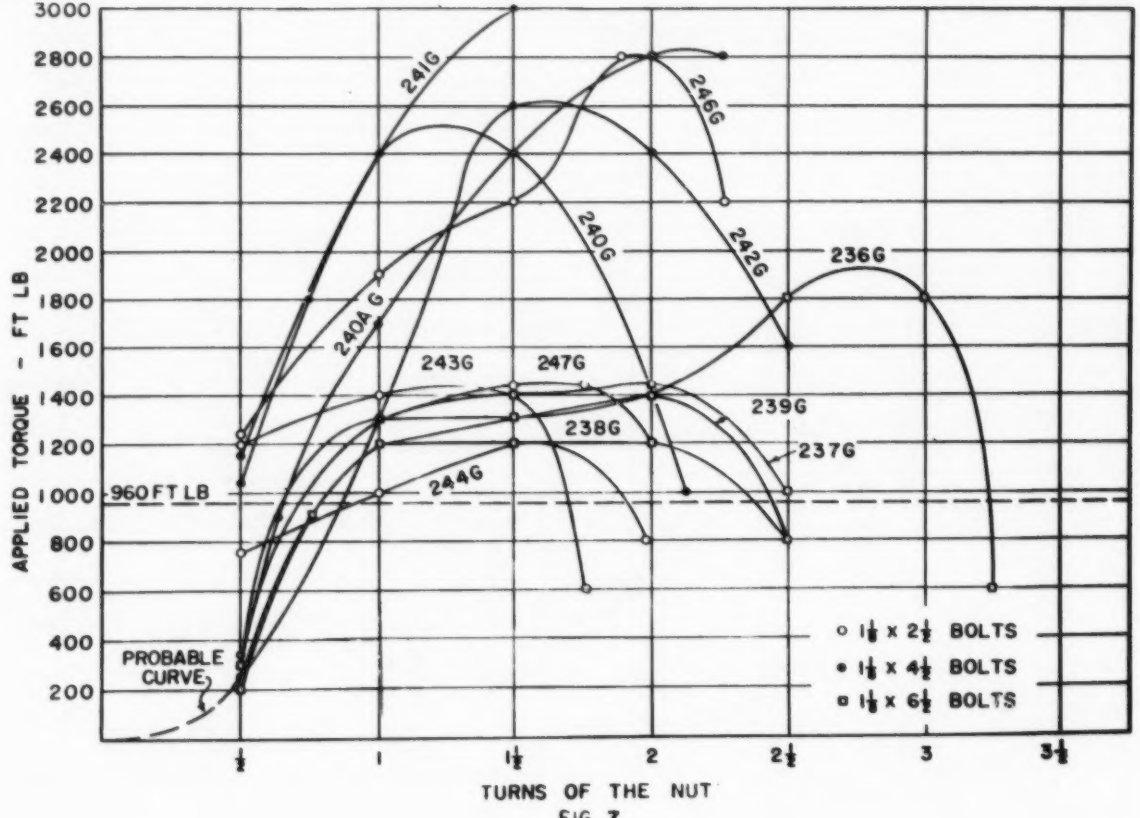

APPLIED TORQUE - FT LB
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
960 FT LB
PROBABLE CURVE
241G
246G
240G
242G
236G
240A G
243G
247G
239G
238G
237G
244G
○ 1⅛ x 2½ BOLTS
● 1⅛ x 4½ BOLTS
□ 1⅛ x 6½ BOLTS
½
1
1½
2
2½
3
3½
TURNS OF THE NUT

FIG. 7

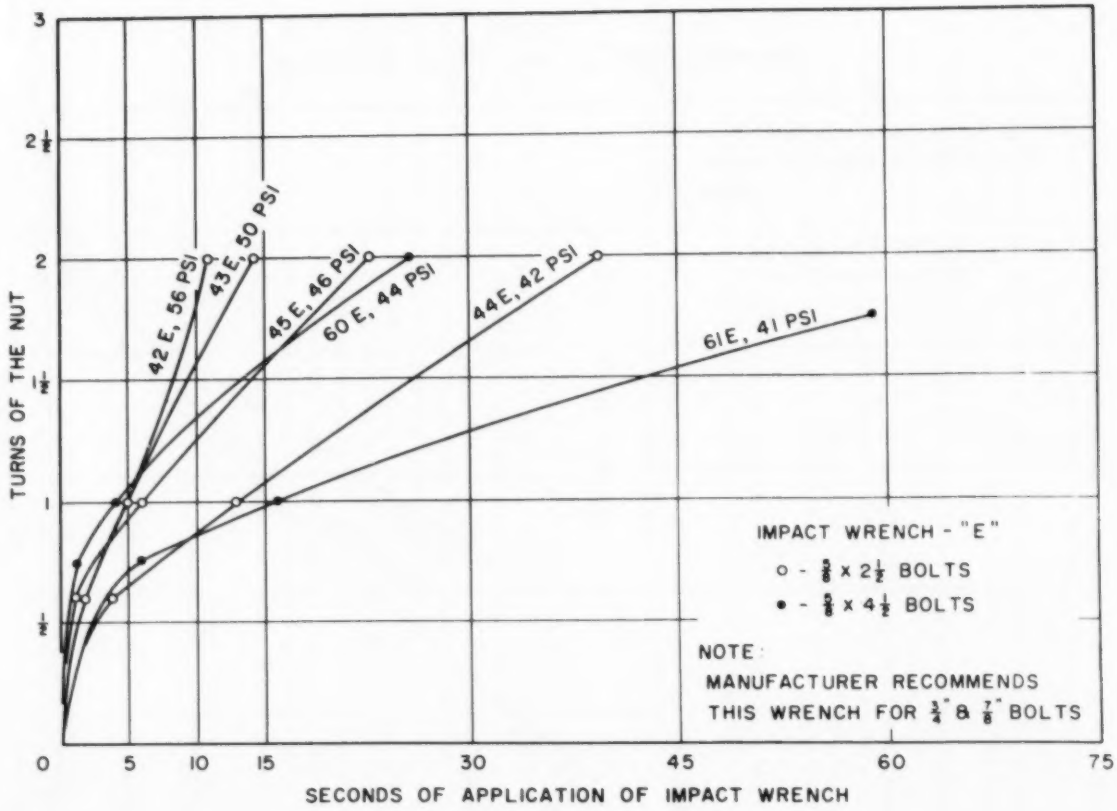

TURNS OF THE NUT
SECONDS OF APPLICATION OF IMPACT WRENCH
0
5
10
15
30
45
60
75
3
2 1/2
2
1 1/2
1
1/2
42 E, 56 PSI
43E, 50 PSI
45 E, 46 PSI
60 E, 44 PSI
44E, 42 PSI
61E, 41 PSI
IMPACT WRENCH - "E"
o - 5/8 x 2 1/2 BOLTS
• - 5/8 x 4 1/2 BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR 1/4" & 7/8" BOLTS

FIG. 8

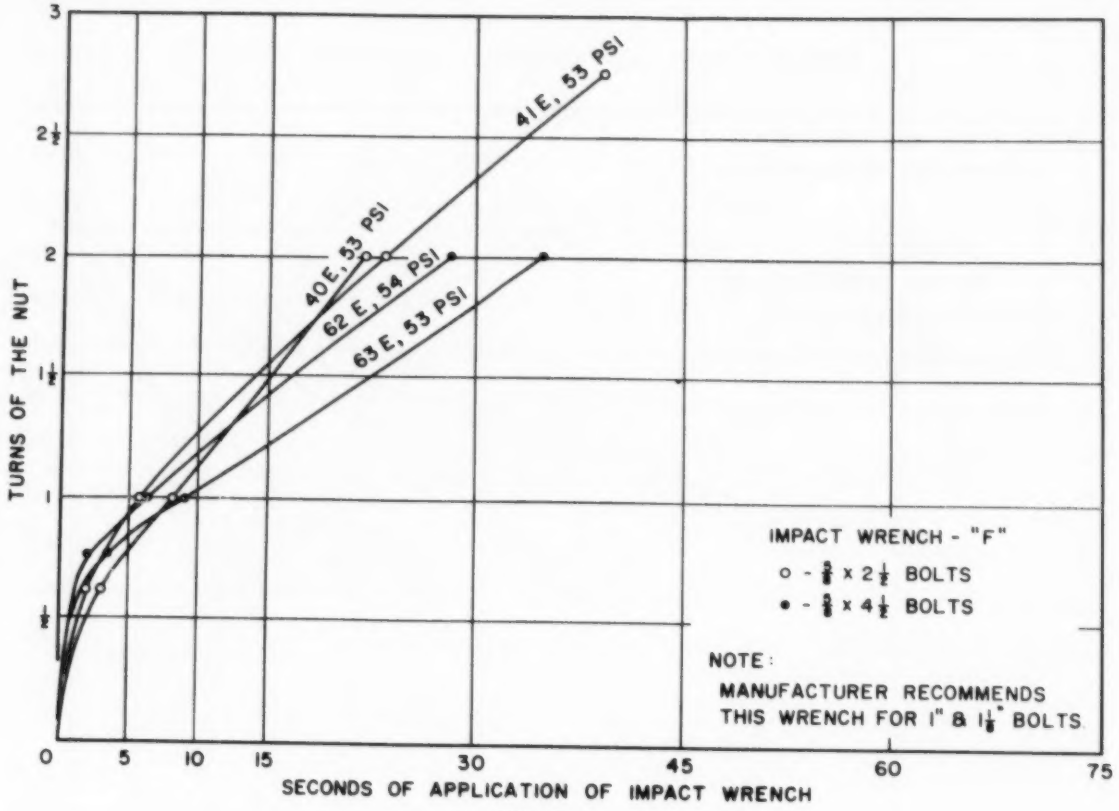

TURNS OF THE NUT
SECONDS OF APPLICATION OF IMPACT WRENCH
41 E, 53 PSI
40 E, 53 PSI
62 E, 54 PSI
63 E, 53 PSI
IMPACT WRENCH - "F"
○ - ⅞ x 2½ BOLTS
● - ⅞ x 4½ BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR 1" & 1⅛" BOLTS
0
5
10
15
30
45
60
75
1
2
3

FIG. 9

2) After the initial tightening, bolts have a tendency to lose a small amount of their clamping force as the joint is worked in service. If bolts are tightened to one full turn initially, this small loss of clamping force still leaves the bolt with a reserve of tension above the minimum.

3) One full turn produces a high prestress in the bolt and consequently a high clamping force on the bolted parts. In a shear-type joint where the load is carried by friction this high clamping force will increase the friction and reduce slip to a minimum. In a joint of this type the stress in the bolts does not change so the fatigue life is very high.

The desirability of having this high clamping force as a prevention against slip was demonstrated by tests at the University of Illinois and reported before the Annual Convention of ASCE on October 20, 1954. A shear-type joint with 4 high strength bolts tightened by turning the nuts 1 1/2 turns withstood more than 2,000,000 cycles of stress from zero to 30,000 psi without slipping into bearing despite the fact that this joint had been coated with grease before assembly.

In joints where the loads are carried in direct tension on the bolts, tests have shown that be increasing the prestress in the bolts the fatigue life is increased.

4) The greatest efficiency of a bolted joint will be obtained with the highest clamping force; and this force is about maximum at 1 turn of the nut.

Use of Impact Wrenches

From the foregoing it is reasonable that one-full turn of the nut from the finger tight position can be the criterion of bolt tension. This means that high strength bolts can be adequately tightened with any tool that can turn the nut one full turn. By far the greatest number of bolts are tightened with impact wrenches so the AAR tests included tightening performance of six different air impact wrenches on various sizes and lengths of high strength bolts.

A typical test set-up is shown on Figure 2 and some of the results obtained are shown on the curves on Figures 8 to 19 incl. where turns of the nut are plotted against seconds of application of the wrench for various air pressures.

It was concluded early in the test program that if 1 full turn of the nut is to be the criterion for bolt tension, the operator of the impact wrench must be able to watch the mark on his chuck and be able to anticipate his wrench shut off at one turn of the chuck. This means that the chuck must turn slowly and steadily. Ten seconds appeared to be a good operating speed. The curves shown in Figures 8 to 19 incl., represent variations of air pressure to secure 1 turn of the nut in about 10 seconds.

Several significant features are evident in these curves. They are as follows:

1) Regardless of the size of bolt or wrench used, 1/2 turn of the nut was obtained in less than five seconds. This applied over a wide range of air pressures. Usually this 1/2 turn came in 2 or 3 seconds which is entirely too fast for an operator to observe and control bolt tightening. A few exceptions to this occurred, but very low pressures were used.

2) There is a definite change in the slope of most of the curves between 0 and 5 seconds indicating a reduction in the rate of nut turning. This slowing down of the chuck is due probably to what has been commonly referred to as wrench "stall." However, when this point is reached the nut does not stop but continues to turn at a relatively constant rate, which eventually breaks the bolt or strips the threads.

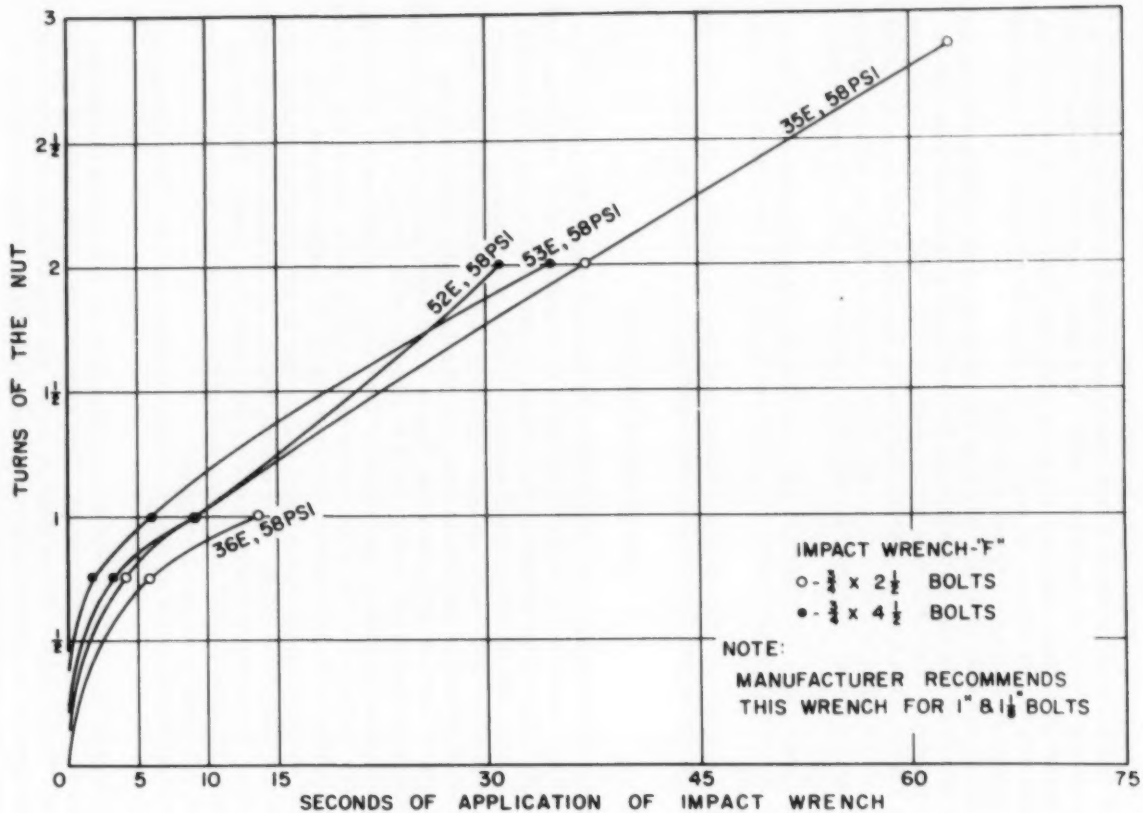

TURNS OF THE NUT
3
2½
2
1½
1
½
0
5
10
15
30
45
60
75
SECONDS OF APPLICATION OF IMPACT WRENCH
35E, 58PSI
52E, 58PSI
53E, 58PSI
36E, 58PSI
IMPACT WRENCH-"F"
o - ¾ x 2½ BOLTS
• - ¾ x 4½ BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR 1" & 1⅛" BOLTS

FIG. 10

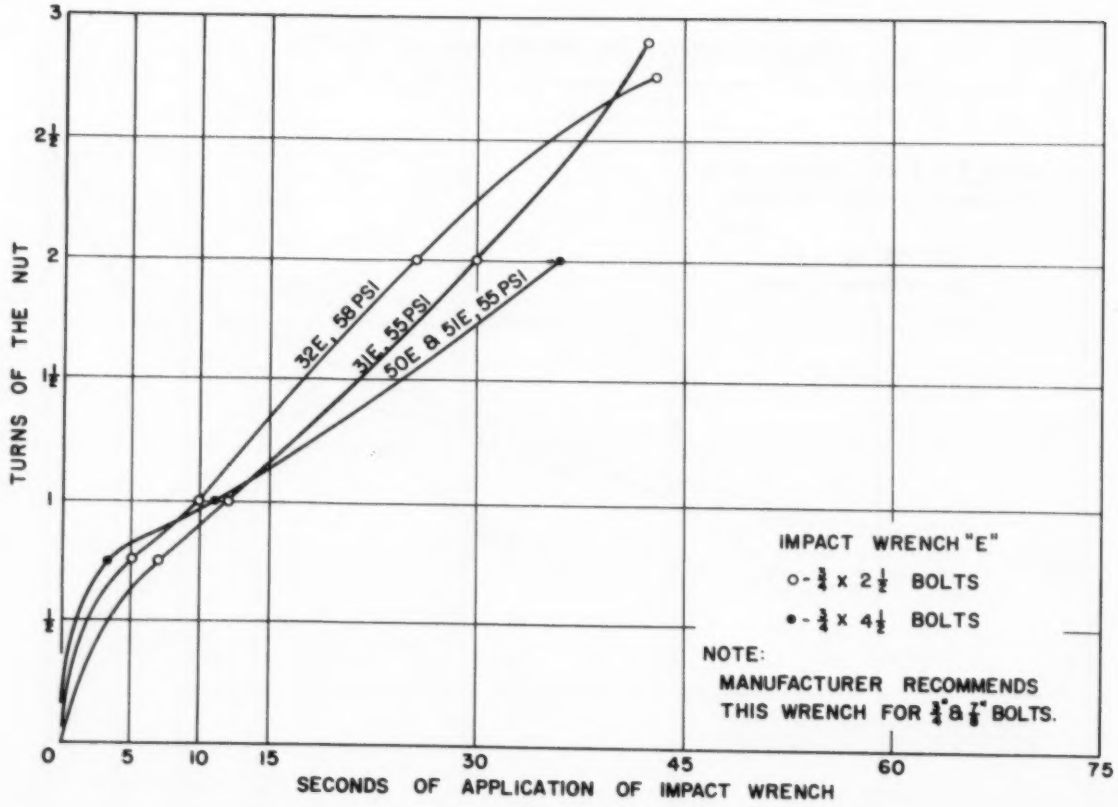

TURNS OF THE NUT
3
2½
2
1½
1
½
0
5
10
15
30
45
60
75
SECONDS OF APPLICATION OF IMPACT WRENCH
32E, 58 PSI
31E, 55 PSI
50E & 51E, 55 PSI
IMPACT WRENCH "E"
○ - ¾ x 2½ BOLTS
● - ¾ x 4½ BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR ¾" & ⅞" BOLTS.

FIG. 11

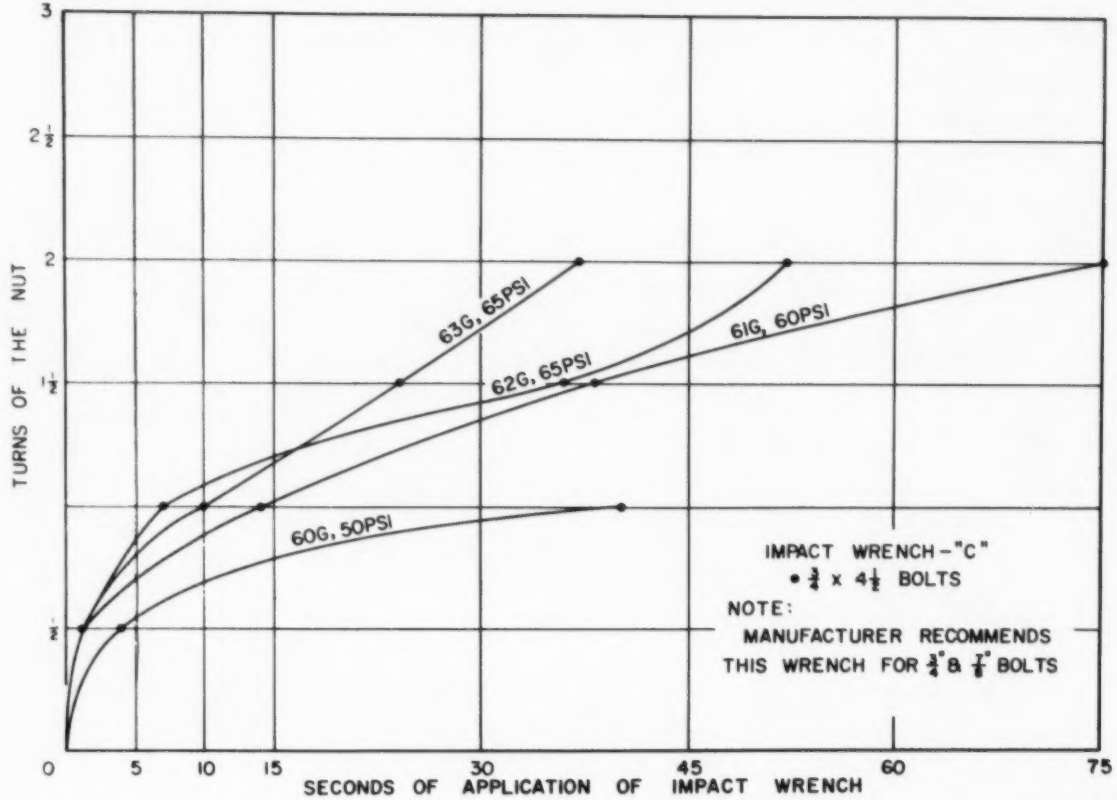

TURNS OF THE NUT
3
2½
2
1½
½
0
5
10
15
30
45
60
75
SECONDS OF APPLICATION OF IMPACT WRENCH
63G, 65PSI
62G, 65PSI
61G, 60PSI
60G, 50PSI
IMPACT WRENCH - "C"
• ¾ x 4½ BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR ¾" & ⅞" BOLTS

FIG. 12

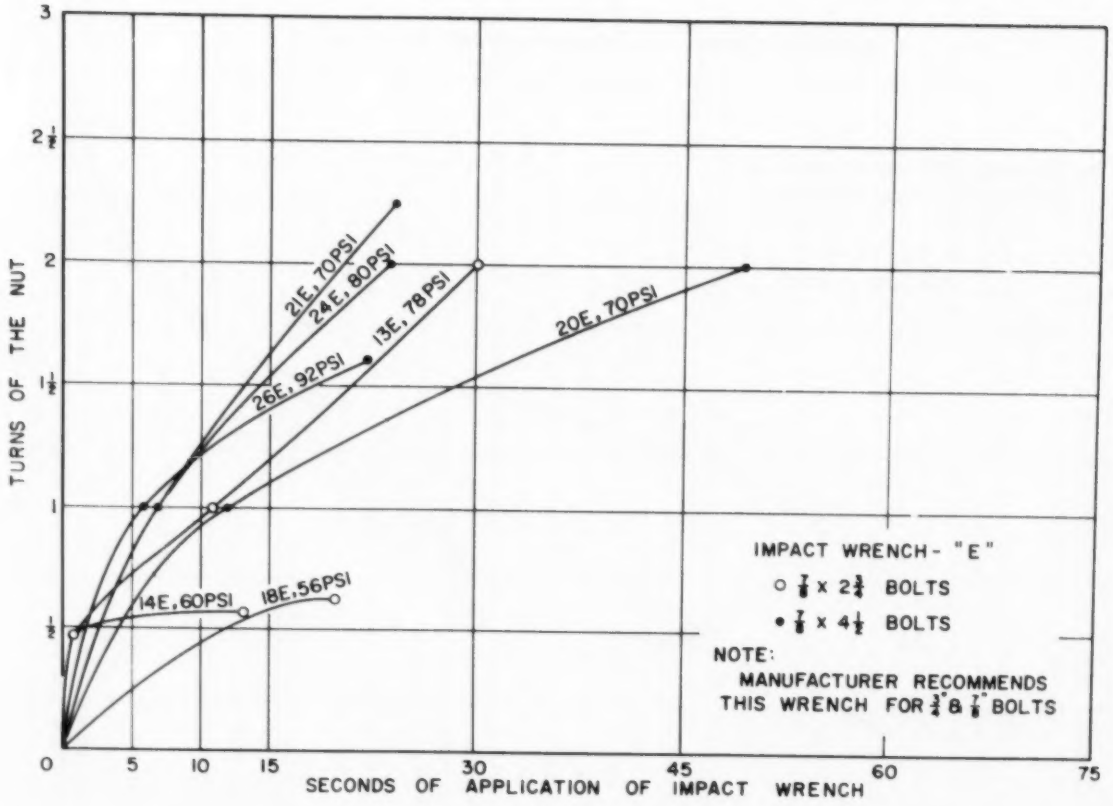

TURNS OF THE NUT
3
2 1/2
2
1 1/2
1
1/2
0
5
10
15
30
45
60
75
SECONDS OF APPLICATION OF IMPACT WRENCH
21E, 70PSI
24E, 80PSI
26E, 92PSI
13E, 78PSI
20E, 70PSI
14E, 60PSI
18E, 56PSI
IMPACT WRENCH - "E"
○ 7/8 x 2 3/4 BOLTS
• 7/8 x 4 1/2 BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR 3/4" & 7/8" BOLTS

FIG. 13

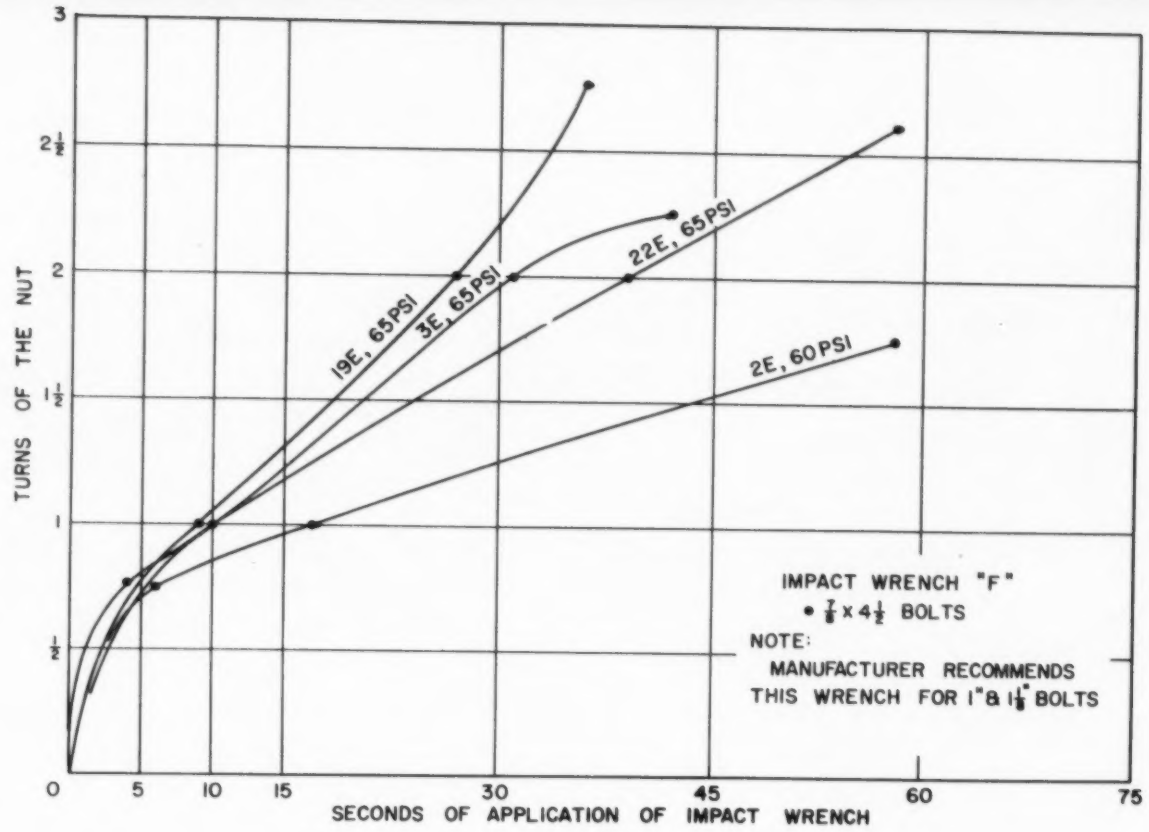

TURNS OF THE NUT
3
2½
2
1½
1
½
0
5
10
15
30
45
60
75
SECONDS OF APPLICATION OF IMPACT WRENCH
19E, 65PSI
3E, 65PSI
22E, 65PSI
2E, 60PSI
IMPACT WRENCH "F"
• ⅞ x 4½ BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR 1" & 1⅛" BOLTS

FIG. 14

3) The general slope of the curves after about 1/2 turn is between 30 and 45 deg from the horizontal. The flatter the curve is, the slower the turning; if the curve is horizontal the chuck has stopped turning completely. The slope of these curves indicates that there was no wrench "stall."

It has already been shown on Figures 3 to 7 incl., that applied torque and consequent bolt tension remain fairly constant after about 1 turn. Therefore, if a wrench is capable of turning a nut once in 10 seconds, it is unlikely that it will "stall" during further turning.

4) Frictional variation between different bolts makes it impossible to secure completely consistent results, but it can be noted in all of these figures that high pressures cause fast nut turning and low pressures slow nut turning.

5) All wrench manufacturers have a certain size wrench that they recommend for use with certain sizes of bolts, but these tests show that by varying the air pressure the same wrench can be used to tighten several sizes of bolts. In Figure 9 for instance, wrench "F" required about 54 psi to tighten 5/8 in bolts to 1 turn in 10 seconds, but on 3/4 in bolts, Figure 10, 58 psi was required and on 7/8 in bolts, Figure 14, 65 psi was required. Similarly, wrench "E" was used on 5/8, 3/4, 7/8 and 1 in bolts, (Figures 8, 11, 13 and 16) and by increasing the pressure from 42 psi for the 5/8 in bolts to 80 psi for the 1 in, this one wrench was adequate for all 4 bolt sizes. Hence by adjusting the air pressure one wrench can be used over a wide range of bolt sizes.

6) 1 1/8-in bolts are not a common size for ordinary structural work, and it was found in these tests that only 1 wrench was capable of tightening 1 1/8-in bolts to 1 turn in 10 seconds. The flat curves shown in Figures 18 and 19 indicate insufficient pressure and very slow nut turning for this size of bolt.

It would be possible to select an optimum air pressure for an individual wrench by repeated tests but such a pressure would only apply to that one wrench. Other wrenches of the same type and make might require more or less pressure. A wrench that has been well maintained will operate differently than one that has been neglected. It seems difficult, then, if not impractical, to assign a definite air pressure figure at which a certain wrench will operate for a certain size of bolt. Such a figure could only serve as a guide to the operator. So many factors enter into the tightening operation that the pressure to be used cannot be predetermined and should not be the governing criterion for bolt tension.

Rather, it is recommended that any convenient pressure be used that will cause the nut to make one turn in about 10 seconds. Any time interval may be used, 8 seconds or 12 seconds, but these tests indicated that 10 seconds represented a good average operating speed.

Field Application of One-Turn Method

The one-turn tightening method is still new and its general application to all field conditions has not yet been proven. However, the American Bridge Company has used this method for the erection of a building in Minneapolis. Impact wrenches were used to tighten the bolts and the general procedure was as follows:

1) Install fitting-up bolts and tighten as required to bring the bolted parts together.

2) Install bolts in the balance of the holes, tighten the nuts finger tight, then give nuts one full turn.

3) Loosen the fitting-up bolts, re-tighten finger tight and give these nuts one full turn.

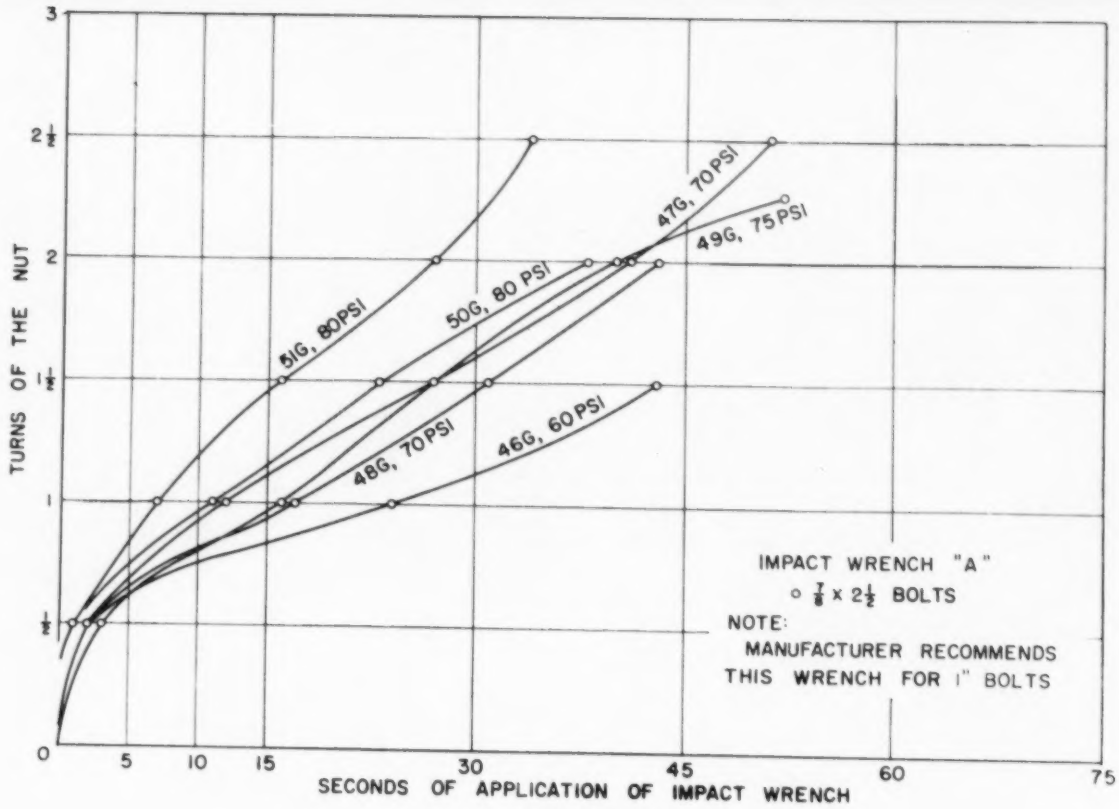

TURNS OF THE NUT
SECONDS OF APPLICATION OF IMPACT WRENCH
0
1/2
1
1 1/2
2
2 1/2
3
5
10
15
30
45
60
75
51G, 80PSI
50G, 80 PSI
47G, 70PSI
49G, 75PSI
48G, 70PSI
46G, 60PSI
IMPACT WRENCH "A"
○ 7/8 x 2 1/2 BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR 1" BOLTS

FIG. 15

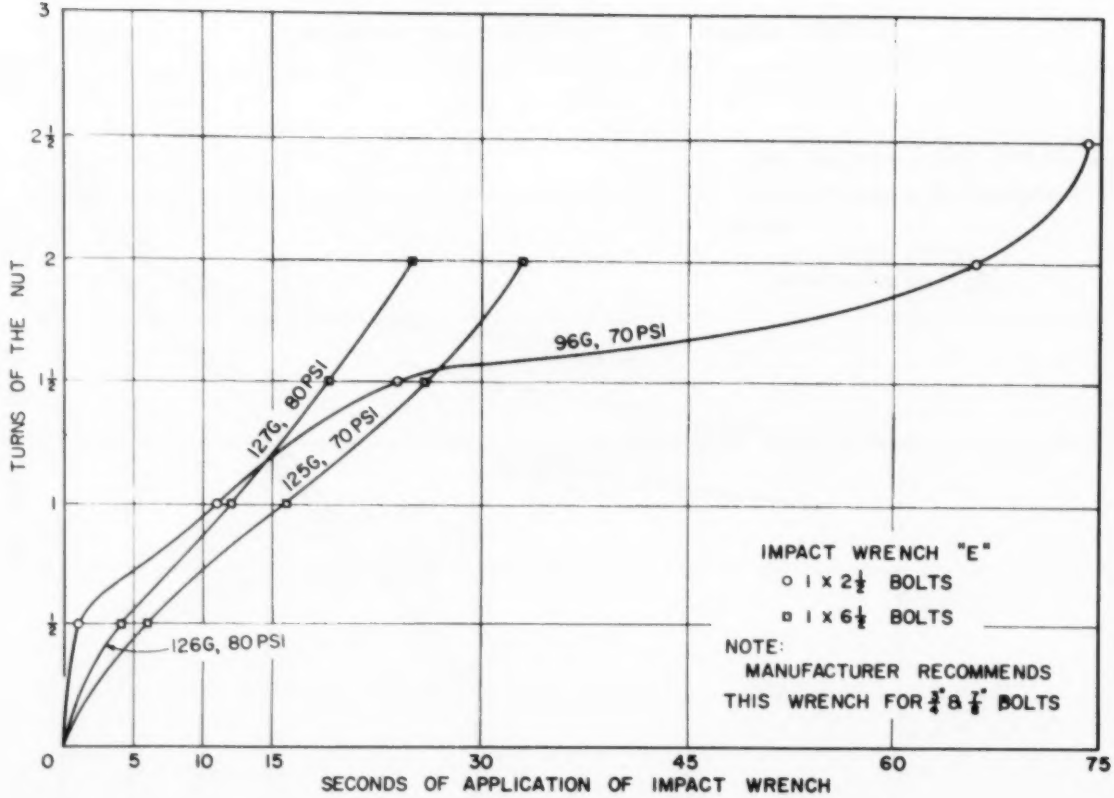

TURNS OF THE NUT
3
2½
2
1¼
1
¼
0
5
10
15
30
45
60
75
SECONDS OF APPLICATION OF IMPACT WRENCH
127G, 80 PSI
125G, 70 PSI
96G, 70 PSI
126G, 80 PSI
IMPACT WRENCH "E"
○ 1 x 2½ BOLTS
□ 1 x 6½ BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR ¾" & 7/8" BOLTS

FIG. 16

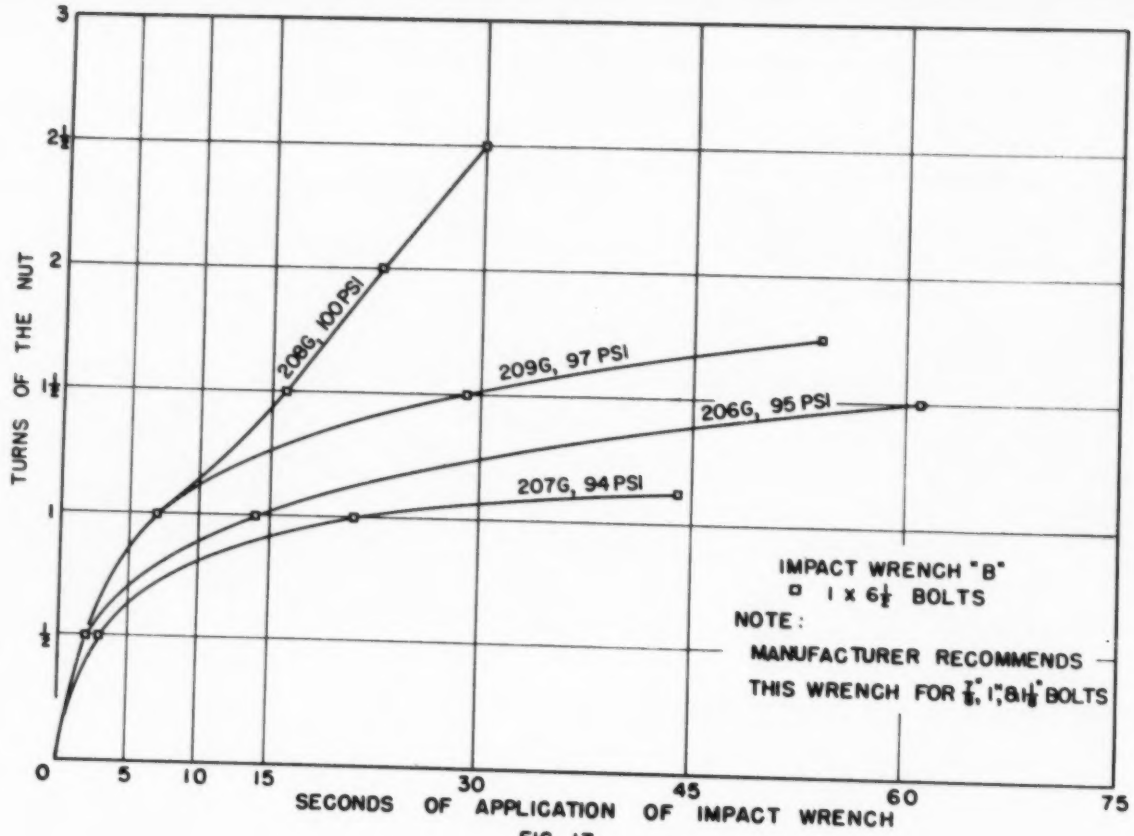

TURNS OF THE NUT
3
2½
2
1½
1
½
0
208G, 100 PSI
209G, 97 PSI
206G, 95 PSI
207G, 94 PSI
IMPACT WRENCH "B"
□ 1 x 6½ BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR ⅞", 1", & 1⅛" BOLTS
0
5
10
15
30
45
60
75
SECONDS OF APPLICATION OF IMPACT WRENCH

FIG. 17

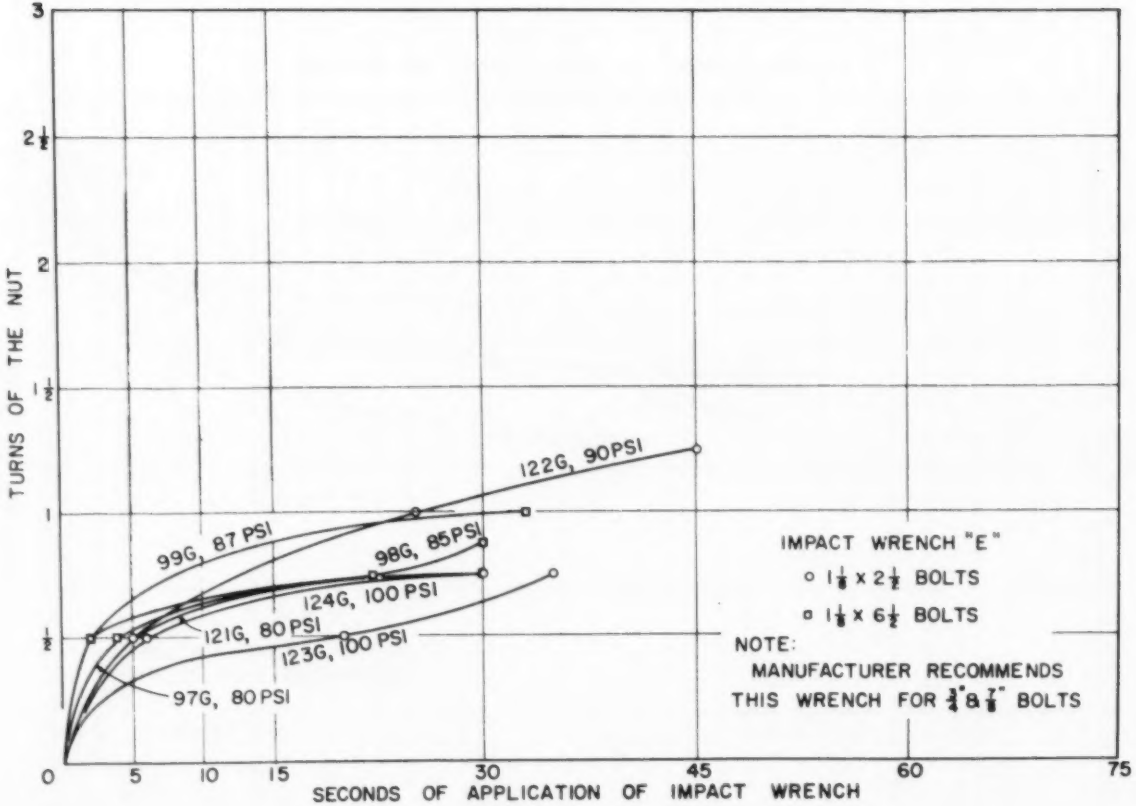

TURNS OF THE NUT
3
2 1/2
2
1 1/2
1
1/2
0
5
10
15
30
45
60
75
SECONDS OF APPLICATION OF IMPACT WRENCH
122G, 90PSI
99G, 87 PSI
98G, 85PSI
124G, 100 PSI
121G, 80 PSI
123G, 100 PSI
97G, 80 PSI
IMPACT WRENCH "E"
o 1 1/8 x 2 1/2 BOLTS
□ 1 1/8 x 6 1/2 BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR 3/4" & 7/8" BOLTS

FIG. 18

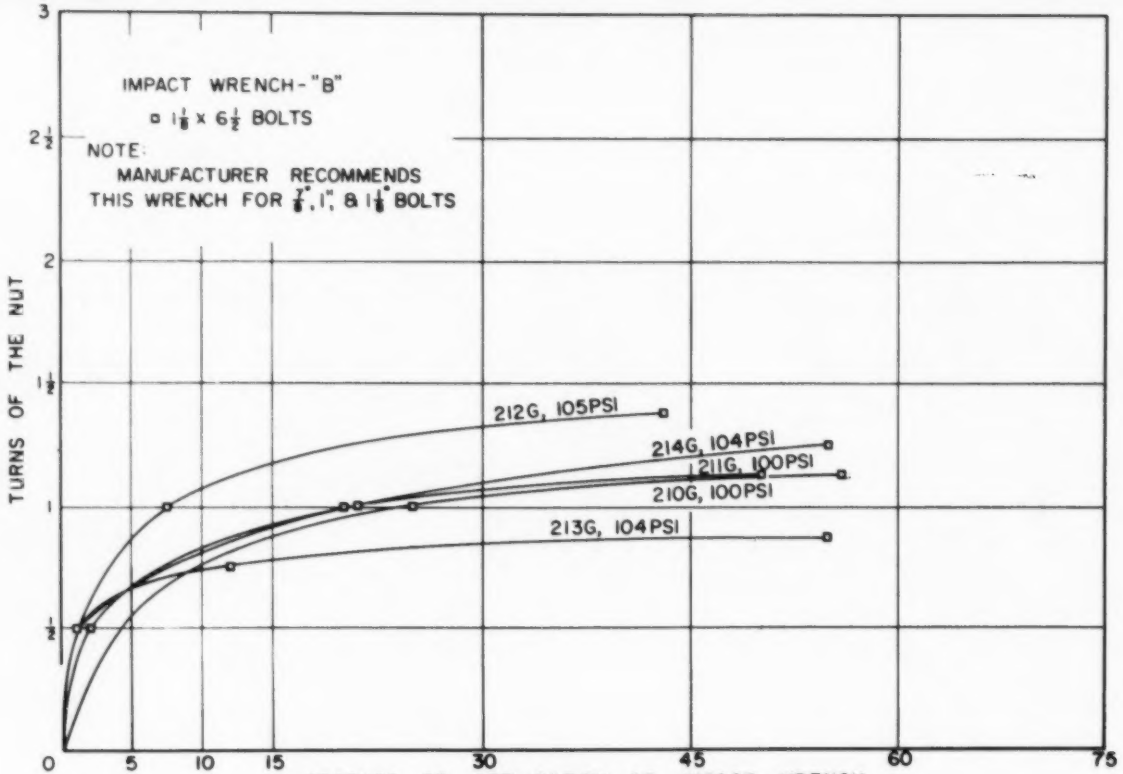

IMPACT WRENCH - "B"
□ 1⅛ x 6½ BOLTS
NOTE:
MANUFACTURER RECOMMENDS
THIS WRENCH FOR ⅞", 1", & 1⅛" BOLTS
212G, 105PSI
214G, 104PSI
211G, 100PSI
210G, 100PSI
213G, 104PSI
TURNS OF THE NUT
SECONDS OF APPLICATION OF IMPACT WRENCH
0
5
10
15
30
45
60
75
½
1
1½
2
2½
3

FIG. 19

No wrench calibration was made and a pressure was used that caused one full turn in about 8 seconds. A check of some of the bolts tightened in this manner showed that bolt tensions considerably above the required minimum were obtained. The method, though new, was readily understood and applied by the wrench operators. After the steel was fitted-up and the nuts were finger-tight, the operator had only to watch a mark on his chuck and when the mark came around for one-full turn the bolt was tight.

It cannot be over emphasized that the bolted parts must be brought together into solid contact bearing before the final tightening is made. Uniform clamping force cannot otherwise be accomplished. Usually, it is not necessary that more than 25 percent of the total number of bolts in the joint be fitting up bolts, but occasionally it may be necessary to use all the bolts as fitting up bolts. Such a condition may exist when the joint is made up of heavy plates and angles or when framing into the webs of large WF beams. When all bolts are necessary for fitting up obviously no one bolt can be loosened to the "finger tight" position and then tightened to the one-full turn. In this case the bolt should be given one-full turn from its tightened position as a fitting-up bolt. It is possible that such bolts may then have a final tightening of as much as 2 full turns, but if failure in the bolt has not occurred during tightening it will not occur in service.

As previously discussed in connection with Table 2, about half of the bolts tested failed by breaking in the shank and the others failed by stripping of the threads. It is considered advisable in the field before any bolts are tightened from a given lot that one or more bolts be tightened to failure, observing the number of turns of the nut required. This will furnish an indication as to how the bolts will be most apt to fail if they are excessively tightened. One-turn tightening will not over-torque the bolt, but one-turn applied to a bolt that already has one or more turns applied to it may result in excessive tightening. Any bolt which would fail by breaking the shank cannot be over-tightened. On the other hand if failure would be by stripping the threads, failure is not immediately apparent as a result of over-tightening, but the stripped threads will cause nearly complete loss of clamping force. It is recommended, therefore, that after a test bolt has been torqued to failure and failure by stripping is indicated, that care be exercised in tightening other bolts that nut turning does not exceed two turns if more than the one-turn tightening is required.

While the one-turn method is particularly useful to those field installations where hand tools can more economically be used, the method is equally effective with power equipment.

CONCLUSION

The American Railroads have approximately 94,000 steel bridges to maintain. The use of high strength bolts to replace hot-driven rivets in field erecting and maintenance can affect a savings to the railroads of about $440,000 a year. Such savings can be realized only when an effective and versatile bolt tightening method is used.

TABLE I

TURNS OF THE NUT FOR MINIMUM BOLT TENSION

BOLT MARK	SIZE AND LENGTH	TURNS OF THE NUT
38E 39E	⅞ ϕ x 2½	1 1
56E 57E	¾ ϕ x 4½	½ ½
27E 28E 29E 30E 36E 13G 14G 15G	¾ ϕ x 2½	7/16 7/16 * 15/16 ½ 7/16 ½ ⅝ 7/16
48E 49E 50E 3G 10G 11G	¾ ϕ x 4½	½ 7/16 ⅝ ½ Ⓢ ½ ⅝ Ⓢ
16G 17G 18G	⅞ ϕ x 2½	½ ⅝ 7/16
8G 9G 12G	⅞ ϕ x 4½	⅝ ⅝ ⅝ Ⓢ
110G 111G 112G 113G 114G	1 ϕ x 2½	⅝ ⅝ ⅝ ⅝ 1

BOLT MARK	SIZE AND LENGTH	TURNS OF THE NUT
145G 146G 147G 71G 72G 73G 74G	1 ϕ x 4½	⅝ Ⓢ Ⓢ ⅝ ⅝ Ⓢ ½ ⅝ ½ ½
83G 84G 85G	1 ϕ x 6½	⅝ ⅝ ⅝
115G 116G 117G 118G 119G	1⅛ ϕ x 2½	9/16 ⅝ 7/16 ⅝ ⅝
128G 129G 130G 131G 148G 149G 150G 151G	1⅛ ϕ x 4½	½ ½ 7/16 ⅝ Ⓢ ½ ⅝ Ⓢ Ⓢ ½ ⅝ Ⓢ
86G 87G 88G	1⅛ ϕ x 6½	⅝ ½

* MISALIGNED HOLES

NOTES:

ALL NUTS "FINGER TIGHT" BEFORE RECORDING TURNS

BOLTS MARKED Ⓢ TIGHTENED THROUGH A 3" SLAB, ALL OTHERS TIGHTENED THROUGH PLATE PLIES.

MINIMUM BOLT TENSION DETERMINED WITH TORQUE WRENCH

⅞" BOLTS TORQUED TO 180 FT LB
1" BOLTS TORQUED TO 320 FT LB
1⅛" BOLTS TORQUED TO 470 FT LB
1¼" BOLTS TORQUED TO 710 FT LB
1⅜" BOLTS TORQUED TO 960 FT LB

TABLE 2

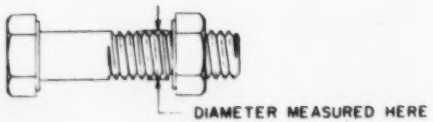
TURNS OF THE NUT REQUIRED TO BREAK BOLTS OR STRIP THREADS

BOLT MARK	SIZE AND LENGTH	TURNS OF THE NUT				
		WITH TORQUE WRENCH		WITH IMPACT WRENCH		
		BREAK	STRIP	BREAK	STRIP	WRENCH USED
40E	⅞ ϕ x 2½				2	F
41E					2⅜	F
56E			3			
57E	⅞ ϕ x 4½	2⅝				
58E					2	D
29E		2⅞				
30E		2½				
31E				2⅝		E
32E				2⅜		E
35E				2⅞		F
36E					2⅜	F
155G		2⅜				
156G		2⅝				
157G		2⅛				
158G	¾ ϕ x 2½	2½				
139G					2½	C
141G				2½		C
142G				3		C
143G				3		C
144G				3		C
43G				3½		A
44G				3		A
45G				3½		A
33G				3½		C
48E		3				
65G					2½	C
3G	¾ ϕ x 4½	2⅝				
167G		2½				
168G		⑤2⅛				
169G		2½ ⑤				
152G		2⅞				
153G		2⅛				
51G	⅞ ϕ x 2½				2½	A
159G		3¼				
160G			3			
161G		3⅛				
53G					2	A
54G					1⅝	A
56G					2½	A
69G					1½ ⑤	A
70G					⑤ 1½	A
162G	⅞ ϕ x 4½		3			
163G			2½			
165G			2			
166G			2½			
170G			⑤2½			
172G		2⅝ ⑤				
135G					2	A
229G		2				
230G			2⅛			
186G					2	B
187G					2½	B
188G	1 ϕ x 2½				2	B
189G					2	B
190G					2½	B
225G		2				
227G			2¼			
228G			2¼			
232G			3			
233G			2⅜			
234G			2			
235G	1 ϕ x 4½	2⅝				
197G					2½	B
216G					2 ⑤	B
208G					2½	B
248G	1 ϕ x 6½		2			
249G			2½			
243G			1¾			
244G	1⅛ ϕ x 2½		2			
246G			2⅛			
247G			2			
221G					2½ ⑤	B
240G	1⅛ ϕ x 4½		2⅛			
242G			2½			
236G			3¼			
237G	1⅛ ϕ x 6½		2½			
238G			2½			
239G			2½			

NOTES: ALL NUTS "FINGER TIGHT" BEFORE RECORDING TURNS.
BOLTS MARKED ⑤ TIGHTENED THROUGH A 3" SLAB, ALL OTHERS TIGHTENED THROUGH PLATE PLIES

TABLE 3

REDUCTION OF BOLT DIAMETER AFTER ONE FULL TURN OF NUT

BOLT MARK	SIZE AND LENGTH	AVERAGE DIAMETER* BEFORE TIGHTENING	AVERAGE DIAMETER* AFTER ONE TURN	DIFFERENCE IN INCHES	PERCENT REDUCTION
38E	$\frac{3}{4}\phi \times 2\frac{1}{2}$	0.616 IN	0.611 IN	0.005	0.81
39E		0.616	0.608	0.008	1.30
34E	$\frac{3}{4}\phi \times 2\frac{1}{2}$	0.746	0.737	0.009	1.47
156G		0.741	0.723	0.018	2.43
157G		0.745	0.729	0.016	2.15
167G	$\frac{3}{4}\phi \times 4\frac{1}{2}$	0.749	0.728	0.021	2.82
160G	$\frac{7}{8}\phi \times 2\frac{1}{2}$	0.862	0.845	0.017	1.97
161G		0.861	0.852	0.009	1.04
1E	$\frac{7}{8}\phi \times 4\frac{1}{2}$	0.856	0.854	0.002	0.23
163G		0.858	0.849	0.009	1.05
166G		0.861	0.859	0.002	0.23
170G		0.857	0.854	0.003	0.35
171G		0.856	0.849	0.007	0.82
228G	$1\phi \times 2\frac{1}{2}$	0.996	0.972	0.024	2.41
229G		0.995	0.965	0.030	3.02
230G		0.996	0.978	0.018	1.81
234G	$1\phi \times 4\frac{1}{2}$	0.983	0.976	0.007	0.71
235G		0.985	0.978	0.007	0.71
215G	$1\phi \times 6\frac{1}{2}$	1.014	1.011	0.003	0.30
249G		0.991	0.986	0.005	0.51
244G	$1\frac{1}{8}\phi \times 2\frac{1}{2}$	1.105	1.086	0.019	1.72
246G		1.109	1.094	0.015	1.36
241G	$1\frac{1}{8}\phi \times 4\frac{1}{2}$	1.098	1.093	0.005	0.46
242G		1.102 IN	1.097 IN	0.005	0.50

* AVERAGE OF TWO DIAMETERS, 90° APART